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**Reduce Fluid Experiment System Flight Data from IML-1**

**by**

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## **BACKGROUND**

The Fluid Experiment System (FES) is a Marshall Space Flight Center flight experiment facility, dedicated to the analysis of crystal growth experiments aboard the space shuttle. FES materials are grown from seed crystals placed in cell chambers filled with liquid growth solution. The cells are installed in a Spacelab double rack and controlled with standard facilities such as power, avionics, air and water, and the results from the forming crystal are recorded with holograms taken at chosen time intervals.

The Holographic Ground System (HGS) at Marshall Space Flight Center is the FES ground support facility for studying solidification processes and fluid dynamics of the crystals by applying optical techniques to the flight holograms. It consists of a 5ft X 16ft air-suspended isolation table, with a vibration damping of  $> 50$  Hz, located in a lightproof room. The table is outfitted with mirrors, beamsplitters, various lenses, and a 50 mW HeNe laser that provide holographic reconstruction of the flight data. The HGS also includes a camera system used for imaging and computer equipment used for image processing and recording. The camera is mounted on a high resolution x-y-z translation mount which has an accuracy of  $1\mu$  per inch of travel, 5 arcseconds of orthogonality, and maximum deviation of  $2\mu$  per 10 cm of travel. The image processing system includes Imaging Technology, Inc. Series 151 software and hardware as well as the Computerized Holographic Image Processing program that allows for recording of the flight data.

## TGS EXPERIMENT

Objectives of the triglycine sulfate [  $(\text{NH}_2 \text{ CH}_2 \text{ COOH})_3 \text{ H}_2\text{SO}_4$  ] (TGS) experiment were as follows: characterization of the growth environment; identification of fluid convection components from crystal growth, residual microgravity, and g-jitter; and correlation of these components with other events in order to further characterize the space shuttle environment and its effects on crystal growth. The primary objective, according to principle investigator Dr. Jim Trolinger, was to "provide a measure of the concentration and concentration gradients in the vicinity of the crystal to support modeling and to help explain the properties of the resulting crystal."

Advantages of the TGS crystal are its ability to operate at room temperature and its ability to detect light wavelengths in the visible and in the infrared range. It does, however, have a slow growth rate which makes it highly susceptible to gravitational influences. It is hoped that in the future researchers will be able to minimize this imperfection by placing the seed in the near convection-free space environment.

In order to characterize the microgravity environment, small spheres were added to the fluid surrounding the crystal seed. They were then tracked and recorded in order to study the particle motion that occurred during a particular time in the experiment. This is known as particle image displacement velocimetry. Researchers hoped that the particles accurately tracked the flow of the fluid in the cell. The diameters chosen were: 199 $\mu$ , 383 $\mu$ , and 646 $\mu$ . These sizes enabled researchers to distinguish each particle from another. The total number of spheres added to the fluid was 26983. Even though the large quantity of particles provided researchers with measurable data, they caused tracking difficulties during shuttle maneuvers.

Dr. Trolinger also decided to incorporate holographic optical elements (HOE's) on the left and right sides of the test cell in order to allow viewing of the crystal at three different angles. One view was straight through the center of the cell, while the other two were at  $\pm 23.5^\circ$ .

## EXPERIMENTAL APPROACH

Non-diffuse and diffuse holograms were produced from direct laser light passing through the cell and from diffuse laser light passing through the cell. From the experiment, Run 1A contributed 114 holograms; Run 1B contributed 133 holograms; and Run 1C contributed 136 holograms. The nature of this contract consisted of reducing the Run 1C diffuse and non-diffuse holograms. The following five tasks were completed during this contract: 1) angular registration was observed and noted at the top and bottom of the left HOE edge between seven diffuse holograms; 2) particles were tracked behind the HOE's from bottom to top of cell for the non-diffuse holograms; 3) seven sets of particle triplets were tracked for the diffuse holograms; 4) particles were tracked from the side view of the HOE's (showing the center image of the crystal) for the non-diffuse holograms; and 5) images were recorded from the diffuse holograms, following the same procedure as in the previous contracts.

The first task consisted of registering six or seven holograms in the normal manner and noting angular registration changes. These changes showed the amount of error involved in recording the holograms. The holograms used were randomly chosen from the diffuse holograms of Run 1C. The left HOE was lined up to the left side of the monitor and recorded as "H1B," the "bottom of the first hologram." Approximately 5000 steps were moved in the y-direction. From here, the top portion of the left HOE was lined up using real-time subtraction, while the change in position was noted. Appendix A shows the entire procedure for this task. To researchers, the changes in position were shown to be minimal.

The second task involved recording the left side HOE images from the non-diffuse holograms. Particles were tracked in the y-direction in each of the holograms. This resulted in seven images being recorded for each hologram, starting from the bottom and moving to the top of the hologram. Appendix A shows the procedure for this task.

The third task involved recording seven sets of particle triplets, tracked throughout the entire run. In the first set of triplets, one large particle and two small particles

approximately orthogonal to each other was tracked, with the particles kept in the same position on the monitor. Dr. Trolinger and Dave Weber decided that it would be best to track one small and two large particles constantly moving in the hologram to accurately depict the fluid movement. This method was used for the remaining particle triplets. The sets of triplets can be found in Figure 1 of Appendix B. A log sheet of the skipped holograms with the crystal sting references can also be found in Appendix B.

The fourth task involved tracking the left side view of the HOE from the non-diffuse holograms. Six images were recorded of the diffracted light from the left HOE. One thousand steps in the y-direction were moved in order to obtain the six images requested. The procedure used can also be found in Appendix A.

Finally, the last task consisted of recording the diffuse images of the holograms of Run 1C. The procedure used was identical to the procedure used in the past. Appendix A contains the procedure for recording those images.

In addition to the above performed tasks, an equipment inventory was prepared and can be found in Appendix C. This is a list of the equipment acquired by FES to aid in the Holographic Ground System research. It will serve as a document for future reference. Specifications of some of the equipment utilized can be found in Appendix D.

The main procedure used for initialization of the CHIP system is discussed in following pages.

## SET-UP PROCEDURE (INITIALIZATION)

Due to storage problems with the optical disk, all of the recorded images were saved on Bernoulli disks and then sent directly to Dr. Trolinger and Dave Weber of MetroLaser for their viewing. All of the above tasks were completed by using the Computerized Holographic Image Processing (CHIP) program to record the images on computer files for velocity/acceleration data. The following modified steps were required to initialize the CHIP program:

1. **MAKE A DIRECTORY OF EACH HOLOGRAM.** Keeping a directory is important so that the image files are not overwritten. The directory name contains the number of the hologram, for example HOE126. Each image is stored into one file in this directory, the filename referring to its location in the image matrix. The filename is in the form *vertical position.angle*, where the *vertical position* is the matrix y-value, and the *angle* denotes the matrix x-value and focus position.
2. **FIND THE REFERENCE POINT.** This step requires focusing on the middle plane, then finding the appropriate starting point on the plane.
  - Use the joystick manually to position the sting at approximately the monitor's center in order to offer a "good" sting view;
  - To focus, flip the x-axis dial to FOCUS and move the joystick in the positive or negative x-direction. The camera is now set at the "B" or middle plane;
  - Flip the x-axis dial back to HORIZONTAL and position the camera on the left HOE.
3. **INITIALIZE THE CHIP PROGRAM FOR USE.** This step connects the CHIP program to the UNIDEX and prepares the files for storing the images.



- On the UNIDEX, press RESET so that the display reads SYS RDY;
- While in the hologram's directory, type CHIP to enter the CHIP program;
- Once in the CHIP program, press UDX ONLINE to connect the program to the UNIDEX;
- Press HOLO CODE and enter the six digits of the hologram name, for example 1CP126;
- Press ANGLE and enter the appropriate angle (1A, HO1, LH1, etc.)
- Move the camera to the desired plane. In this case it is already centered in the "B" plane (middle).

There are separate procedures for the previously mentioned tasks. They can be located in Appendix A. At the conclusion of each procedure, the film must be replaced with the next succeeding hologram.

## **CONCLUSIONS**

Hopefully, from the study of the images, researchers can gain better knowledge of particle motion and crystal growth in low-gravity environments. They hoped to do so by incorporating holographic optical elements into the cell to provide three different angles in which to observe particle movement. From previous images, researchers concluded that g-jitter was possibly a function of time and spatial coordinates. With the images from the holographic optical element area, researchers can use the new angles provided to correlate them with the previous sets of holographic images in order to gain a 3-D view of the cell and its environment. Figures 1, 2, and 3 of Appendix E show the 3-D view of the cell that researchers are studying, while Appendix F shows the HGS optical bench and system layout used to reconstruct and record the cell images.

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# **APPENDIX A**

## **IMAGE ACQUISITION PROCEDURES**

## ANGULAR REGISTRATION PROCEDURE FOR HOLOGRAMS 2T1CP197-2T1CP216

Place hologram 2T1CP197 onto the film holder.  
Line up left HOE with the left side of the monitor.  
Record the image.  
Save bottom image as "H1B."  
Move Y approximately 5000 steps (1 step = 5  $\mu$ m).  
Save top image as "H1T."  
Return to bottom.  
Align hologram 2T1CP200 to "H1B."  
Note X,Y registration difference.  
Save as "H2B."  
Move Y approximately 5000 steps.  
Align hologram 2T1CP200 to "H1T."  
Note X,Y registration difference.  
Save as "H2T."  
Return to bottom.  
Repeat the above steps until hologram 2T1CP216 is reached.

IMAGE ACQUISITION PROCEDURE FOR THE LEFT HOE IMAGES FROM THE RUN  
1C NON-DIFFUSE HOLOGRAMS

Using the UNIDEX, move the camera to the reference point on the image. While in the appropriate directory, enter the CHIP program. If the camera is not in the correct plane of focus, move to it now.

CM TRANSLATION  
HOLOCODE  
ANGLE HO1  
AUTOGRAB  
INC X -4700  
INC Y 1905  
GO  
INC X 0  
INC Y -1162  
GO  
ANGLE HO2  
INC Y -1162  
GO  
ANGLE HO3  
INC Y -1162  
GO  
ANGLE HO4  
INC Y -1162  
GO  
ANGLE HO5  
INC Y -1162  
GO  
ANGLE HO6  
INC Y -1162  
GO  
ANGLE HO7  
INC Y -1162  
GO  
AUTOGRAB OFF  
RESET X,Y  
AUTO UNIDEX OFF  
UNIDEX ONLINE OFF  
EXIT  
EXIT

IMAGE ACQUISITION PROCEDURE FOR THE "DIFFRACTED LIGHT" LEFT  
HOE IMAGES FROM THE RUN 1C NON-DIFFUSE HOLOGRAMS

Using the UNIDEX, move the camera to the reference point on the image. While in the appropriate directory, enter the CHIP program. If the camera is not in the correct plane of focus, move to it now.

CM TRANSLATION  
HOLOCODE  
ANGLE LH1  
INC X 900  
INC Y 0  
GO  
INC X 0  
INC Y -1000  
GO  
ANGLE LH2  
INC Y -1000  
GO  
ANGLE LH3  
INC Y -1000  
GO  
ANGLE LH4  
INC Y -1000  
GO  
ANGLE LH5  
INC Y -1000  
GO  
ANGLE LH6  
INC Y -1000  
GO  
AUTOGRAB OFF  
RESET X,Y  
AUTO UNIDEX OFF  
UNIDEX ONLINE OFF  
EXIT  
EXIT

## IMAGE ACQUISITION PROCEDURE FOR THE RUN 1C DIFFUSE HOLOGRAMS

Using the Unidex, move the camera to the reference point on the image.  
While in the appropriate directory, enter the CHIP program.  
If the camera is not in the correct plane of focus, move to it now.

CM TRANSLATION  
HOLOCODE  
ANGLE 1B  
AUTOGRAB  
INC X 500  
GO  
INC X 0  
INC Y -1405  
GO (4 TIMES)  
ANGLE 2B  
INC X 1827  
INC Y 0  
GO  
INC X 0  
INC Y 1405  
GO (4 TIMES)  
ANGLE 3B  
INC X 1827  
INC Y 0  
GO  
INC X 0  
INC Y -1405  
GO (4 TIMES)  
AUTOGRAB OFF  
RESET X,Y  
AUTO UNIDEX OFF  
UNIDEX ONLINE OFF  
EXIT  
EXIT

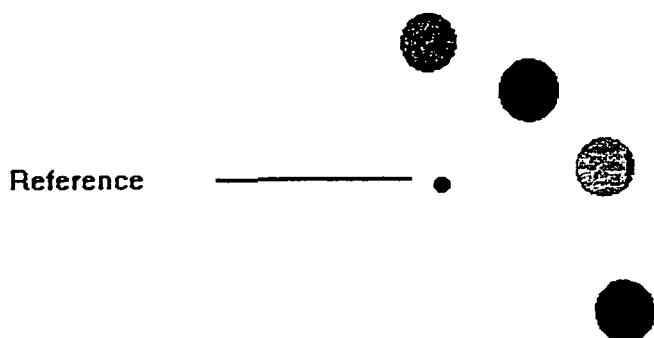


**APPENDIX B**

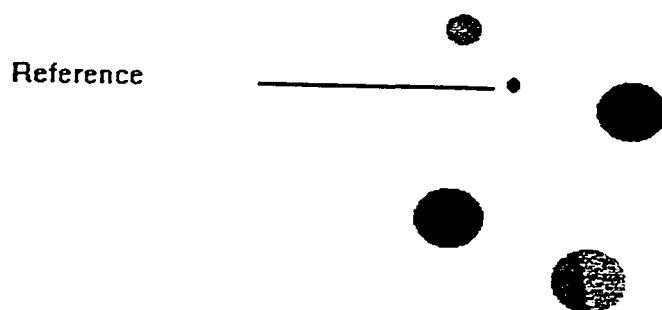
**PARTICLE TRIPLETS DRAWINGS AND DATA**

Figure 1

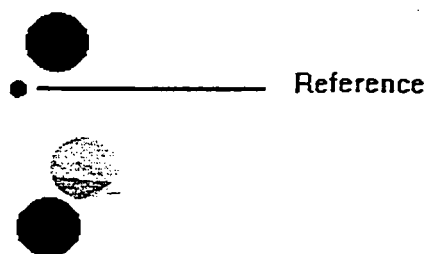
SET 2 TRIPLETS



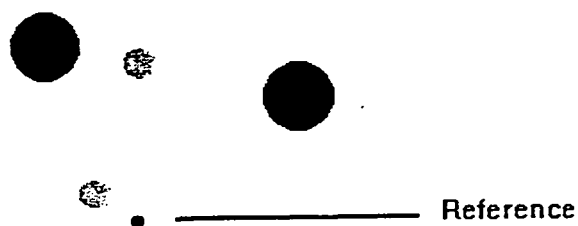
SET 3 TRIPLETS



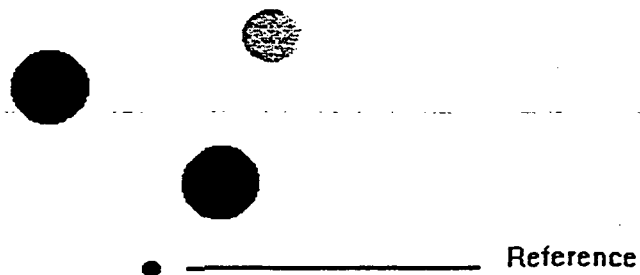
SET 4 TRIPLETS



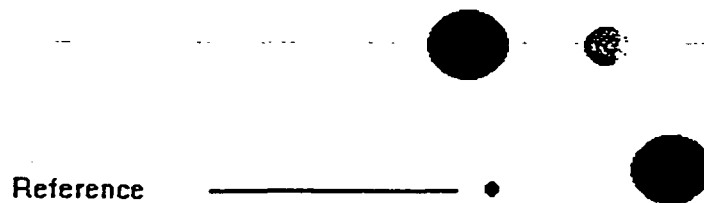
SET 5 TRIPLETS



SET 6 TRIPLETS



SET 7 TRIPLETS



## TRIPLETS LOG SHEET

### SET 1

#### Skipped Holograms:

2T1CP090 -cut in half

### SET 2

#### Skipped Holograms:

2T1CP090 -cut in half

2T1CP174 -could not locate small sphere

2T1CP180 -too dark

2T1CP197 -could not locate small sphere

#### Sting Reference:

2T1CP126 -> X = 0, Y = 1119

2T1CP171 -> X = 0, Y = 1119

2T1CP185 -> X = 0, Y = 1119

### SET 3

#### Skipped Holograms:

2T1CP090 -cut in half

#### Sting Reference:

2T1CP126 -> X = 0, Y = 843

2T1CP171 -> X = 0, Y = 843

2T1CP210 -> X = 0, Y = 843

2T1CP231 -> X = 0, Y = 843

### SET 4

#### Skipped Holograms:

2T1CP078 -too dark

2T1CP132- 2T1CP246 -impossible to locate small sphere

#### Sting Reference:

2T1CP126 -> X = 2113, Y = 5619

### SET 5

#### Skipped Holograms:

NONE

#### Sting Reference:

2T1CP099 -> X = -1443, Y = 1413

2T1CP126 -> X = -1276, Y = 1228

2T1CP185 -> X = -823, Y = 1153

## SET 6

Skipped Holograms:

NONE

Sting Reference:

2T1CP138 -> X = -338, Y = 4508

2T1CP222 -> X = -1922, Y = 4578

2T1CP240 -> X = -2036, Y = 4568

## SET 7

Skipped Holograms:

2T1CP188 -too dark

Sting Reference:

2T1CP105 -> X = -5653, Y = 4437

2T1CP132 -> X = -5473, Y = 4513

2T1CP182 -> X = -5346, Y = 4484

2T1CP225 -> X = -5457, Y = 4513

**APPENDIX C**  
**EQUIPMENT LIST**

**Pages Missing From Available Version:**

**A11 through A14**

# Table Optics Specifications

COMPONENT	SIZE	FLATNESS	INCIDENT ANGLE	WEDGE ANGLE	FRONT COATING	BACK COATING	TRANSMISSION	REFLECTANCE
Mirror 1	8"D x 1.25"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Mirror 5	8"D x 1.25"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Mirror 10	8"D x 1.25"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Mirror 11	8"D x 1.25"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Mirror 12	8"D x 1.25"th	$\lambda/20$	22.5°	<10 min	Dielectric	-	-	>98%
Mirror 6	8"D x 1.25"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Spare Mirror 3	8"D x 1.25"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Mirror 4	6.25" x 4.5" x 1.0"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Mirror 3	6.25" x 4.5" x 1.0"th	$\lambda/10$	26°	<10 min	Dielectric	-	-	>98%
Spare Mirror 2	6.25" x 4.5" x 1.0"th	$\lambda/20$	45°	<10 min	Dielectric	-	-	>98%
Mirror 2	6.325"D x 1"th	$\lambda/20$	11°	<10 min	Dielectric	-	-	>98%
Spare Mirror 1	6.325"D x 1"th	$\lambda/20$	11°	<10 min	Dielectric	-	-	>98%
Beamsplitter 1	9"D x 1.25"th	$\lambda/20$	45°	<10 min	Dielectric	AR "V"	50%	50%
Beamsplitter 3	9"D x 1.25"th	$\lambda/20$	45°	<2 sec	Dielectric	AR "V"	50%	50%
Beamsplitter 2	6.325"D x 1"th	$\lambda/20$	8°	<10 min	Dielectric	AR "V"	50%	50%
Beamsplitter 4	9"D x 1.25"th	$\lambda/20$	45°	<2 sec	Dielectric	AR "V"	25%	75%
AR "V" : a multilayer antireflective coating that reduces the reflectance to near-zero for one specific wavelength								

## NEWPORT EQUIPMENT SPECIFICATIONS

### **Model 675T Beam Steering Instrument**

Fine Elevation Angle Range:	-20° to +7°
Elevation Angle Resolution:	15 arc sec
Fine Azimuth Angle Range:	15°
Azimuth Angle Resolution:	8 arc sec

### **Model AMB-2 Adjustable Mounting Base**

Translation Ranges:	Top Plate:	0.5 in (13 mm)
	Slotted Base Plate:	1.75 in (45 mm)

### **Model 400 Dual-Axis Translation Stage**

Orthogonality:	1 mrad
Runout:	< 5 μm
Load Capacity:	Horizontal: 100 lb (45 kg)
	Vertical: 8 lb (3.6 kg)

### **Model 420-1S Translation Stage**

Stage Travel:	1 in (25 mm)
Runout:	< 5 $\mu$ m
Load Capacity:	66 lb (30 kg)

### **Model 36-S Tilt Platform**

Tilting Range:	-4.3° to +7°
Rotation Range:	+/- 2.5°
Resolution:	2 arc sec

### **Model 496 Precision Power Rotary Table**

Resolution:	0.001°
Accuracy:	0.01°
Backlash:	< 30 arc sec
Load Capacity:	350 lbs (160 kg)
Stall Torque:	3500 in-lb (3977 kg-cm)



### **Model 280 Laboratory Jack**

**Range:** 3-6 in (75-152 mm)

### **Model 845 Digital Shutter System**

**Shutter Aperture:** 5.6 mm  
**Shutter Response Time:** < 3 ms  
**Exposure Duration:** 10 ms - 990 s  
**Timing Accuracy:** 0.05% +/- 10 us  
**Max. Repetition Rate:** 10 Hz  
**Operating Modes:**

<b>TIME:</b>	Timed shutter opening
<b>MANUAL:</b>	Open & close shutter independent of time setting
<b>START:</b>	Initiates timed or manual exposure
<b>RESET:</b>	Closes shutter
<b>DELAY:</b>	Optional 10 s delay before shutter opening

**Pushbutton Cable:** 96 in (2.44 m)  
**Power:** 115 V @ 0.1 A or 230 V @ 0.05 A  
**Controller Dimensions:** 3.25 X 6 X 6.25 in

### **Model 20Z20 Round Zerodur Mirror**

**Diameter:** 2.000 in (50.80 mm)  
**Thickness:** 0.500 in (12.70 mm)  
**E<sub>MAX</sub>:**  $\lambda/20$   
**Scratch & Dig:** 15-5

### **Model 40Z20 Round Zerodur Mirror**

**Diameter:** 4.000 in (101.60 mm)  
**Thickness:** 0.6907 in (17.70 mm)  
**E<sub>MAX</sub>:**  $\lambda/20$   
**Scratch & Dig:** 20-10

### **Model 520 Film Plate Holder**

**Capability:** Holds plates up to 5 in. (127 mm) wide

## **Newport Model 815 Power Meter**

### **READOUT**

Meter:	3-1/2 digit LCD with LO BAT
Ranges:	0.002, 0.02, 0.2, and 2 mW
Accuracy:	+/- 5% NBS traceable absolute radiometric accuracy
Repeatability:	+/- one digit
Linearity:	+/- one digit
Analog Output:	rear panel connector provides 1.999 V full scale; Output Impedance- 10K ohm
Analog Output Bandwidth:	180 KHz
Power:	9 V supplied by six AA alkaline cells with nominal 300 hour life
Case:	3.25" H x 6.06" W x 6.25" D

### **DETECTOR**

Spectral Response:	400 nm - 1060 nm
Active Area:	1 cm <sup>2</sup> effective aperture
Maximum Continuous Input:	100 mW/cm <sup>2</sup>
Responsivity:	35 mA/W typical @ 850 nm
Risetime:	170 nanoseconds
Acceptance Angle:	(at 5% fall off) +/- 45° (no filter) +/- 12.5° (with filter)
Cable:	96" BNC

## **ORIEL EQUIPMENT SPECIFICATIONS**

### **Model #1625 Precision Translator**

Range: 25 mm w/graduations every 0.01 mm  
Resolution: 0.25  $\mu$ m

### **Model #1636 Precision Vertical Translator**

Range: 25 mm w/graduations every 0.01 mm  
Resolution: 0.25  $\mu$ m

### **Model #1643 Precision Rotator**

Coarse Adjust: 360°  
Micrometer Sine Drive Range: 24° w/graduations every 0.55 arc min  
Resolution: 1 arc sec

## ROLYN OPTICS EQUIPMENT SPECIFICATIONS

### **Model 20.0109 Achromat**

Diameter:	21.0 mm
Focal Length:	40.0 mm
Center Thickness:	7.8 mm
Edge Thickness:	3.0 mm
Scratch & Dig:	80-50
Centration:	3 arc min

### **Model 20.0255 Achromat**

Diameter:	37.0 mm
Focal Length:	120.0 mm
Center Thickness:	10.2 mm
Edge Thickness:	7.0 mm
Scratch & Dig:	80-50
Centration:	3 arc min

### **Model 20.0310 Achromat**

Diameter:	31.7 mm
Focal Length:	220.0 mm
Center Thickness:	8.0 mm
Edge Thickness:	6.1 mm
Scratch & Dig:	80-50
Centration:	3 arc min

## AEROTECH EQUIPMENT SPECIFICATIONS

### **Model ATS100-200 Positioning Stage Specifications**

Total Travel:		200 mm (8 in)
Mechanical Drive System:		Precision ground ballscrew
Linear Resolution (2 mm lead):		1 $\mu\text{m}$ (40 $\mu\text{in}$ ) @2000 steps/rev motor resolution (0.1 $\mu\text{m}$ to 10 $\mu\text{m}$ available)
Max. Travel Speed:	Stepping Motor DC Servo Motor HAL Option	50 mm/sec (2 in/sec) 100 mm/sec (4 in/sec) 25 mm/sec (1 in/sec)
Max. Load Carrying Capability:	Horizontal Vertical Side	22.7 kg (50 lbs) 10.0 kg (22 lbs) 11.4 kg (25 lbs)
Accuracy:	Standard HAL Option	+/- 6 $\mu\text{m}$ (+/- 240 $\mu\text{in}$ ) +/- 1 $\mu\text{m}$ (+/- 40 $\mu\text{in}$ )
Repeatability:	Standard HAL Option	+/- 0.7 $\mu\text{m}$ (30 $\mu\text{in}$ ) bi-directional +/- 0.3 $\mu\text{m}$ (12 $\mu\text{in}$ ) bi-directional
Straightness and Flatness of Travel:		
		<u>Standard</u> <u>HAL</u>
	Differential	2 $\mu\text{m}/25\text{ mm}$ 1 $\mu\text{m}/25\text{ mm}$
	Maximum Deviation	+/- 3 $\mu\text{m}$ 1.75 $\mu\text{m}$
Nom. Stage Weight:	W/out Motor W/ Motor	1.2 kg (2.6 lbs) 2.8 kg (6.1 lbs)

### **Model AOM 110-2 Gimbal Optical Mount**

Resolution:	0.15 arc sec
Clear Aperture:	1.82 in
Range:	+/- 5°
Diameter:	2.00 in
Thickness:	0.50 in

### **Model AOM 110-4 Gimbal Optical Mount**

Resolution:	0.08 arc sec
Clear Aperture:	3.75 in
Range:	+/- 5°
Diameter:	4.00 in
Thickness:	0.75 in

### **Model 110-6 Gimbal Optical Mount**

Resolution:	0.06 arc sec
Clear Aperture:	5.68 in
Range:	+/- 4°
Diameter:	6.00 in
Thickness:	1.18 in

### **Model 110-8 Gimbal Optical Mount**

Resolution:	0.044 arc sec
Clear Aperture:	7.63 in
Range:	+/- 4°
Diameter:	8.00 in
Thickness:	1.59 in

### **Model 130-9 Gimbal Optical Mount**

Resolution:	0.031 arc sec
Clear Aperture:	8.62 in
Range (rotational freedom):	360° azimuth & elevation
Diameter:	9.00 in
Thickness:	1.63 in

### **Model 130-9M Motor-driven Gimbal Optical Mount**

Resolution:	0.188 arc sec
Clear Aperture:	8.62 in
Range:	360° azimuth & elevation
Repeatability:	0.75 arc sec
Diameter:	9.00 in
Thickness:	1.63 in

### Model ATT 185-5 Precision Tilt Table

Range:		+/- 10°
Resolution:		0.1 arc sec
Load Carrying Capability		
	Horizontal:	10 lbs (4.54 kg)
	Vertical:	10 lbs (4.54 kg)
Weight:		3.1 lbs (1.41 kg)

### Model ARS 301 Rotary Positioning Table

Resolution:		0.1 arc sec
Load-Carrying Capability		
	Horizontal:	25 lbs (11.36 kg)
	Vertical:	15 lbs (6.82 kg)
Clear Aperture:		2.68 in

### Model ATS 303M ACCUDEX Series Positioning Stage

Range:		76.2 mm
Resolution:		0.025 $\mu$ m
Window:		82.5 mm X 50.8 mm
Load Carrying Capability		
	Horizontal:	22.73 kg
	Vertical:	9.09 kg
Linear Scales & Vernier:		0.02 mm

### Model ATS 302MM ACCUDEX Series Linear Positioning Stage

Range:		50 mm
Resolution:	200 steps/rev:	2 $\mu$ m
	400 steps/rev:	1 $\mu$ m
Load carrying Capability		
	Horizontal:	45.5 kg
	Vertical:	9 kg
Repeatability:		0.6 $\mu$ m
Accuracy:		2.5 $\mu$ m /25 mm
Straightness & Flatness of Travel:		2.5 $\mu$ m /25 mm
Maximum Allowable Motor Speed:		10 rev/sec

## Spectra Physics Model 125A 50 mW HeNe Laser Specifications

### OUTPUT

Wavelength:	632.8 nm
Power (TEM <sub>00</sub> ):	50 mW

### BEAM CHARACTERISTICS

Beam Diameter (1/e <sup>2</sup> ):	1.8 mm
Beam Divergence:	0.6 mrad

### OPTICS

Output Mirror:	G3814-001
High Reflector:	G0005-003

### RESONATOR CHARACTERISTICS

Transverse Mode:	TEM <sub>00</sub>
Degree of Polarization:	1 x 10 <sup>3</sup>
Angle of Polarization:	Vertical +/- 5°
Resonator Configuration:	Long radius
Cavity Length:	177 cm
Axial Mode Spacing:	85 MHz
Plasma Excitation:	DC:25-35 mA @ 6kV RF Option: 15 W @ 40.68 MHz

### AMPLITUDE STABILITY

Beam Amplitude Noise (1-100 kHz):	2% rms (0.3% w/RF option)
Beam Amplitude Ripple (1-120 kHz):	0.5% rms (0.5% w/ RF option)
Long Term Power Drift:	< 5% over 8 hours
Warm-up Time:	1 hour

### ENVIRONMENTAL CAPABILITY

Operating Temperature:	10°C-40°C (50°F-105°F)
Altitude:	Sea level to 3000 m (10,000 ft)
Humidity:	Below dew point

### POWER REQUIREMENTS

Voltage:	115/230 V +/- 10%, 50-60 Hz
Power:	450 W

### PHYSICAL CHARACTERISTICS

Weight:	Laser Head:	45.5 Kg (100 lb)
	Power Supply:	13.6 Kg (30 lb)
Shipping Weight:		79.5 Kg (175 lb)
Dimensions:		6 x 13 x 18 in. 152.4 x 330.2 x 457.2 mm
Cable Length (Power Supply to Laser):		1.8 m (6 ft)



**APPENDIX E**  
**HOE DRAWINGS**

# Full View of Cell

Input Side  
Window

Output Side  
Window

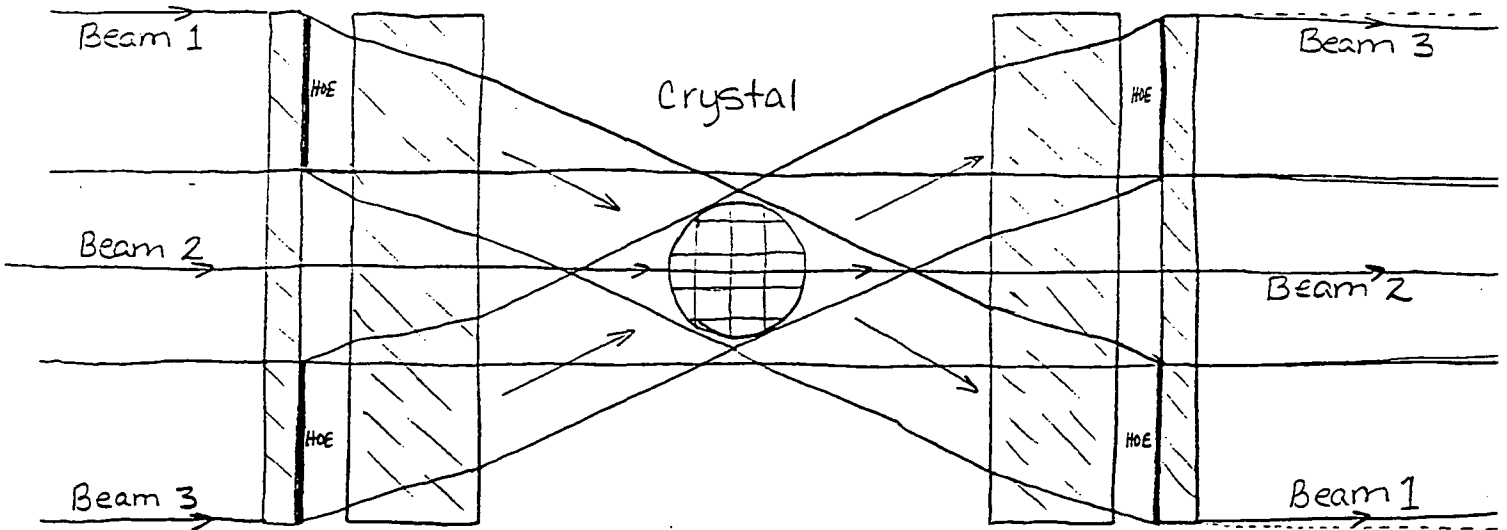
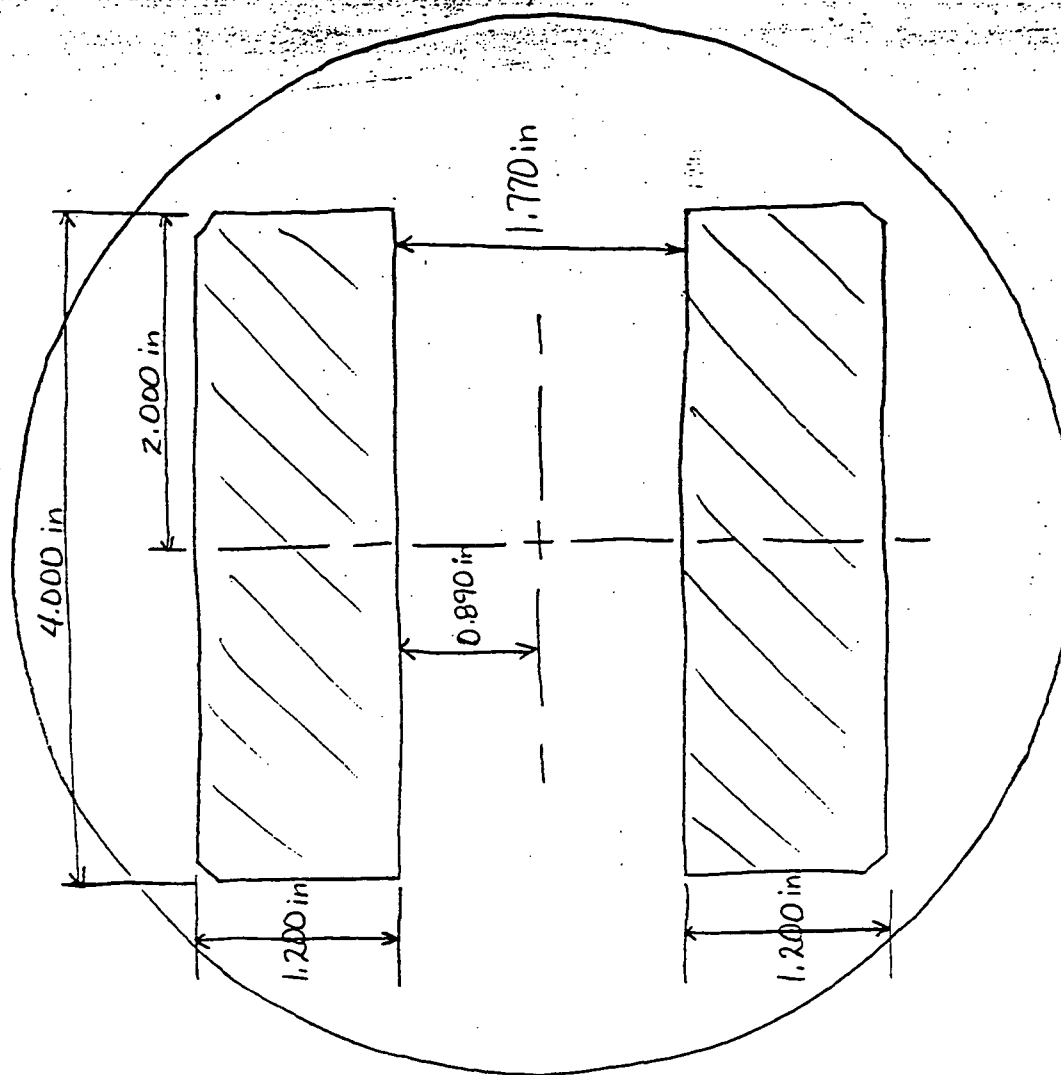


Figure 1

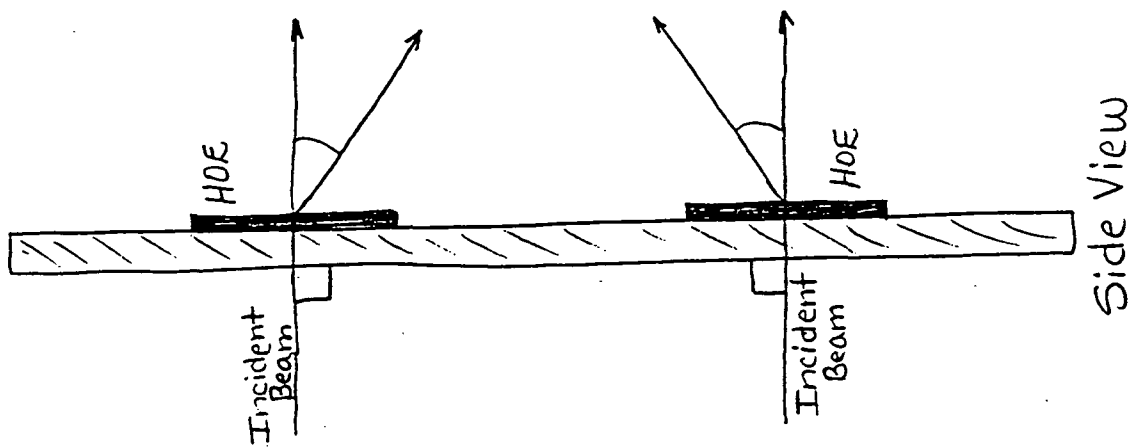
# Cell Dimensions



Front View of  
Cell

Figure 2

Input HOE's



Output HOE's

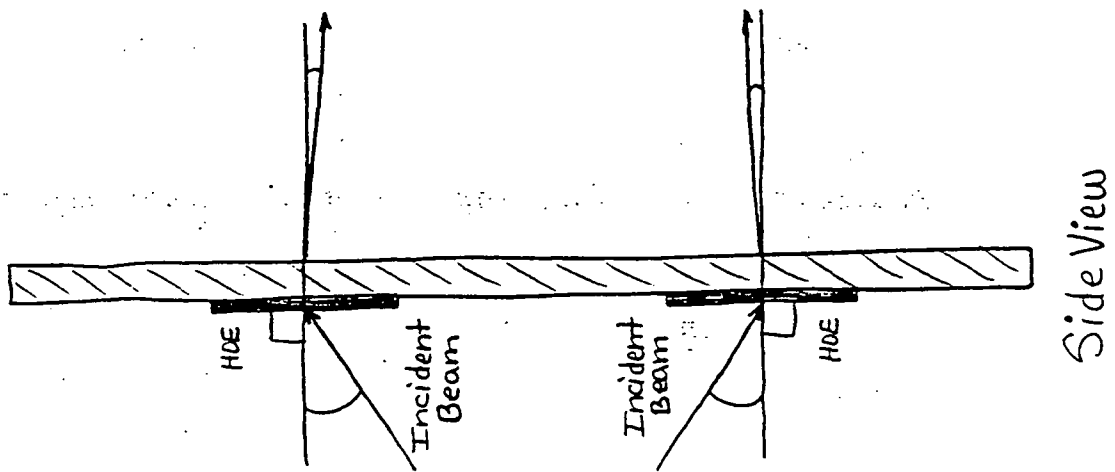
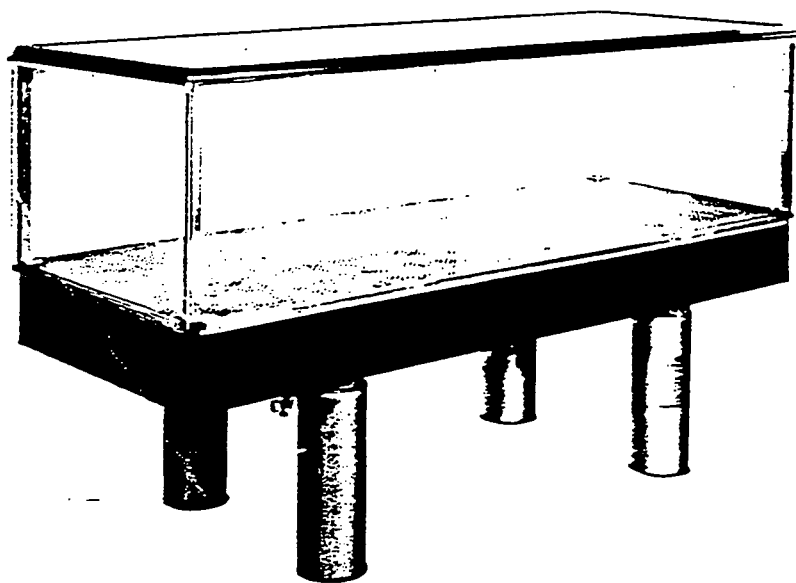


Figure 3

# **APPENDIX F**

## **MISCELLANEOUS ILLUSTRATIONS**

# HGS Optical Bench



The diagram illustrates the optical setup for the program reconstruction experiment. It features a central rectangular region containing a beam splitter (BS3) and a lens (L2). A light source (LS) is at the bottom left, connected to a series of mirrors (M1, M2, M3, M4, M5, M6, M10, M11, M12) and beam splitters (BS1, BS4). A half-wave plate (HH1) and a polarizing beam splitter (PBS) are also shown. The setup is labeled with various components like A1, A2, A3, A31, SM2, SF, TM1, TM2, LB1, LB2, LB3, ND3, and M14.

A31